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Tracer Test Implementation and Analysis in Order to Evaluate Reinjection Effects in Lahendong Field

Teguh Prabowo, Dhanie M. Yuniar, Sigit Suryanto, Marihot Silaban

Pt Pertamina Geothermal Energy, Skyline Tower. 14th Fl., Jl. MH Thamrin no. 9, Jakarta 10340, Indonesia.

teguh.prabowo@pertamina.com, dhanie.marstiga@pertamina.com, sigitsuryanto@pertamina.com, marihot@pertamina.com,

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ABSTRACT

Lahendong field production which started in 2001 has been gradually expanded to its current capacity of 80 MWe. Brine and condensate fluids are re-injected back into the reservoir through LHD-7 cluster at low temperature. Changes in characteristics of production fluids from several wells have been observed. Tracer tests were conducted to further study the results and effects of reinjection. Tracers found in production fluids indicate different rate of breakthrough to production wells. Presented is the 2013 Lahendong tracer test including the planning, execution, and monitoring. Effects of reinjection fluid that has been observed are also presented here.

1. INTRODUCTION

Lahendong Geothermal Field is located about 20 km south of Manado, North Sulawesi, Indonesia. The area is situated in a large volcanic area with big caldera (Tondano and Pangolombian Caldera) and surrounded by active volcanoes (M. Lokon, M Mahawu, M. Pangolombian, M. Lengkoan, M. Kauratan and M. Tampusu) with altitude of 750 m to 900 m above sea level. Geothermal explorations in Lahendong first started in 1971 by New Zealand – Indonesian Team which obtained geological map and proposed drilling targets. Geological, geophysical and geochemical survey by Vulcanological Survey of Indonesia (VSI) indicated high temperature geothermal resource in the region. As a follow-up, three shallow wells LH1, LH2 and LH3 were drilled to depths less than 500 meters around Linau Lake by Indonesian Volcanology Division.

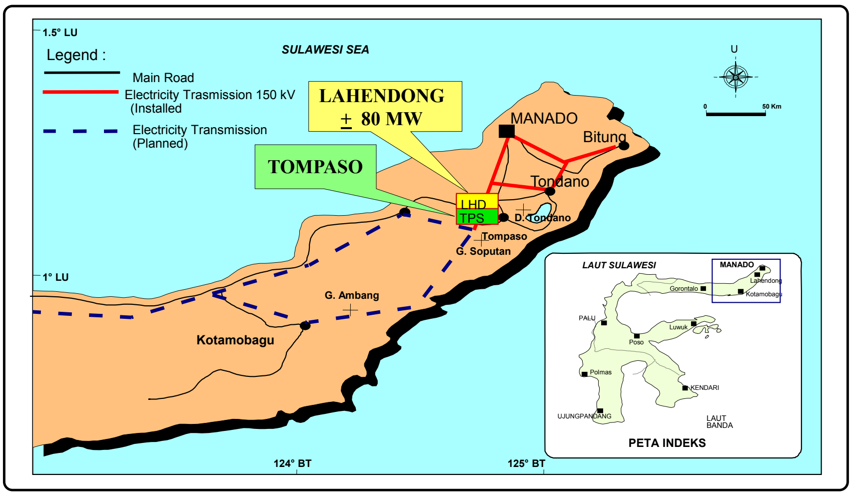

Figure 1: Lahendong Location Map

After 1986, exploration activities and development of this field managed by Pertamina and Pertamina Geothermal Energy (subsidiary company of Pertamina) lead to development plan of 80 MWe electricity generation consisted of 4 power plant units. In 2001, first unit was commissioned and producing 20MWe electricity until present, followed by second unit in 2007, third unit in 2009 and fourth unit in 2012. Production of this field is around 1100 t/h with 600 t/h of steam and 500 t/h of brine from 10 production wells. Lahendong field implements cold injection system with brine and condensate injection combined in one injection cluster (Cluster LHD-7) which consists of three injection wells. The temperature of Lahendong Field is in the range of 280 – 320 ^{o}C with separated production zone between north zone and south zone. The north zone produced two-phase fluid with dryness ranging from 30 – 50 %, whereas the south zone produced drier fluid with dryness ranging 80 – 100 %.

In order to determine the effect of injection to the reservoir, two tracer injection surveys were conducted in Lahendong field. First survey was implemented in 2006 by using tritium as tracer fluid. The last survey was performed last year using NDSA as tracer fluid. The tracer injection survey objectives are determining injection fluid path, breakthrough time, mass recovery and thermal breakthrough to the reservoir.

This paper focus on the result and analysis from the most recent tracer injection survey held in 2013 with consideration from the result of the survey of 2006.

2. THE TRACER INJECTION METHOD AND ANALYSIS

There are several types of tracer, fluorescein, radioisotope and chemical tracer. Compared with other tracers, radioisotope is the finest regarding the detection ability in very low concentration and the low initial concentration of the fluid in the reservoir. However, the most common tracer fluid used in geothermal fluid is chemical tracer. Tracer fluids used for the survey should not react with reservoir rocks, easy to be analyzed, could hold temperature of reservoir and have very low availability in the reservoir. Several aspects to be considered in designing tracer injection survey are the tracer fluid type, the amount of the tracer injected, and the sampling frequency.

The latest tracer injection survey used naphthalene di sulfonate acid (NDSA) as tracer fluid. 100 kg of 1.6 NDSA were dissolved in 1000 liters of water with pH 6 - 7 and solubility 25 % before injected into well LHD-7. The wellhead pressure of LHD-7 was -0.7 bar and the injection was 300 t/h cold fluid with temperature of 40 ^oC.

There were eight production wells sampled and monitored for tracer detection based on the geological location of the wells from the injection well and represent every cluster on both production zones. Results observed from the samples are tracer concentration versus time and plotted as tracer profile curve. The curve could inform the breakthrough time correlated with maximum velocity of the tracer fluid, maximum tracer concentration indicates average velocity of the tracer fluid, width of dispersion curve indicates amount of dispersion of tracer fluid in reservoir and tracer recovery as function of time. The tracer profile curve of Lahendong Field in 2013 is shown by figure 3 below.

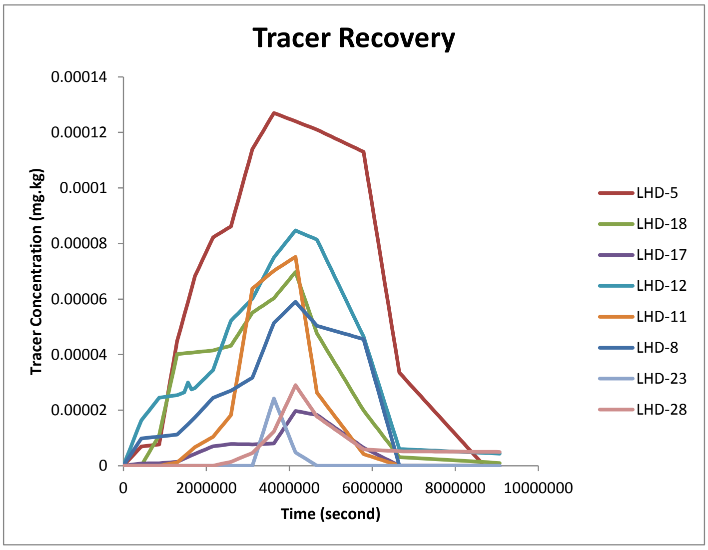

Figure 3: Tracer Profile Curve of Lahendong Field 2013

Method used for analyzing tracer data quantitatively for determining mass recovery, breakthrough time, temperature decline and thermal breakthrough of production wells is based on Axelsson et al (1995). This method uses fluid flow in fracture media model and for the calculation, the tracer inverse simulator (TRINV) from Icebox Package is used. The fluid is assumed to be flowing in a single channel fracture with linear flow pattern and fulfilling mass conservation law. The TRINV software applies curve fitting with non-linear least square method to calculate the parameters. The input parameters of the software are tracer concentration by time, the distance between injector and producer, production rate, and injected tracer mass. The output parameters are tracer velocity (u), coefficient of dispersion (D), recovery factor (RF) and flow path area (AØ).

The model by Axelsson et al consider dispersion factor on the fluid flow in the reservoir. The fluid flow model is influenced by advection, and convection generate the fluid flow, mechanical dispersion represent real fluid velocity and molecular diffusion induce the fluid flow from high to low concentration. However, fluid flow in reservoir could not be generated due to pore or fracture wall effect, pore or fracture width effect and flow path tortuosity effect. Considering the effects, the tracer curve profile analysis in this paper is a semi-analytical calculation that does not have a very high accuracy, nevertheless passably for preliminary interpretation of temperature as the effect of injection.

Thermal breakthrough defined as the time when reservoir temperature first decline due to the injection. The analysis suse temperature decline and thermal breakthrough model developed by Axelsson et al (1995). The model considers heat transfer convectively along flow path area and conductively in the reservoir rocks. The assumptions used in this calculation are that temperature decline and thermal breakthrough in a production well are affected only by injection fluid.

3. RESULT AND ANALYSIS

Based on tracer profile curve (figure 3), all production well monitored is affected by the injection from well LHD-7. This paper emphasizes on the result of well LHD-5 and LHD-8 that represent two production zone, north bock and south block. Furthermore, the wells also have several different characteristics. LHD-5 produces more liquid while LHD-8 produces drier fluid. LHD-8 has been producing since power plant unit 1 started on 2001 while LHD-5 started to produce for power plant Unit-3 on 2009. Since the injection pad is located at northern boundary of the field, LHD-5 location is closer than LHD-8 ti the injection cluster. This would make the study important for make-up well targeting in north area for power plant unit 3 and 4 and evaluate the actual reinjection strategy. Besides that, tracer study would be essential for wells in south area in which no injection well is nearby. The well location and direction of Lahendong Field is shown in figure 4.

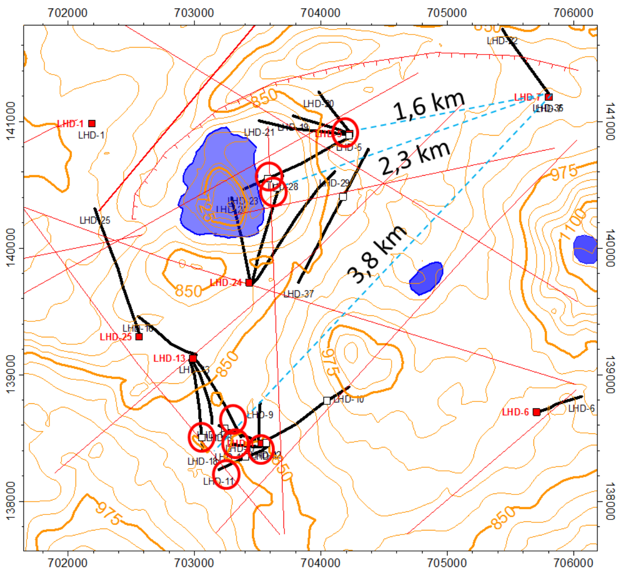

Figure 4: Well Direction and Location of Lahendong Field

Tracer profile, injection well and production well data of Lahendong Field used for input of TRINV shown in table 1 below.

Table 1: Tracer Profile, Injection Well and Production Well Data.

Injection Well	LHD-7
Production Rate, q (kg/s)	83.3
Injection Temp, Ti (deg-C)	40
Tracer Mass Injected, M (kg)	100
Tracer Type	1,6 NDSA

Production Well	LHD-5	LHD-8
Distance from Injection Well, Xe (km)	1.6	3.6
Production Rate, Q (kg/s)	31.7	8.4
Temperature, T (deg-C)	280	320

Using TRINV software with the input from table 1 and figure 3, the curve fit model of tracer profile curve for well LHD-5 and LHD-8 could be derived and shown in figure 5 below.

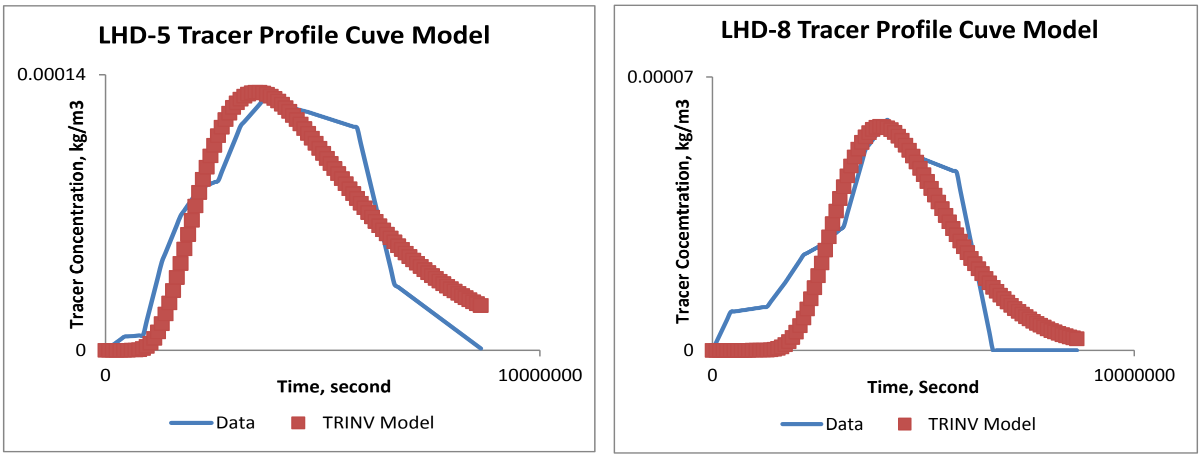

Figure 5: Curve Fit Model of Tracer Profile Well LHD-5 and LHD-8

The calculation result from the software based on the curve fit model shown in table 2 below.

Based on the results, there is no apparent difference in breakthrough time between LHD-5 and LHD-8 although the last well has more distance from injection well and lower mass recovery than LHD-5. This indicates that there is direct a connection between LHD-8 to the injection well that could be represented as a connecting fracture. However, the fracture could be in small size due to mass recovery of LHD-8.

After the parameters of the tracer analysis are available, the next step is the thermal decline and breakthrough prediction of production wells. The calculation should consider that the injected fluid has lower temperature leading temperature decline in the flow path zone and not all the injected fluid flow into the production wells, so the mass recovery of the production well generated from tracer analysis would be the input for the calculation. The other inputs for the prediction are initial reservoir temperature of each wells, injected fluid temperature and injection rate scenarios. The prediction of temperature decline for several injection scenarios are shown in figure 6.

Table 2: Calculation Result

Production Well	LHD-5	LHD-8
Distance from Injection Well, Xe (km)	1578	3497
Production Rate, Q (kg/s)	31.7	8.4
Recovery Factor, (%)	19.7	1.6
Flow velocity, u (m/s)	4.01E-04	8.29E-04
Combined mass parameter, m (kg/m2)	0.248	0.159
Dispersion Coeff, Dtr (m2/s)	7.71E-02	1.49E-01
Flow Path Area, AØ (m2)	42.2	1.7
Maximum concentration, kg/m3	1.31E-04	5.73E-05
Time at max concentration, second	3.49E+06	4.01E+06

As shown in the figures, LHD-5 would suffer significant temperature decline affected from the injection well. The breakthrough time of LHD-5 is rapid with injection rate above 50 kg/s. the breakthrough shows in the first year after injection started and the temperature would decline more than 30 ^{o}C after 30 years of injection. In contrast, the injection only slightly affect LHD-8 in the south. The temperature decline is less than 20 ^{o}C after 30 years injection although the injection rate is around 100 kg/s. breakthrough time is 2 years after the injection started.

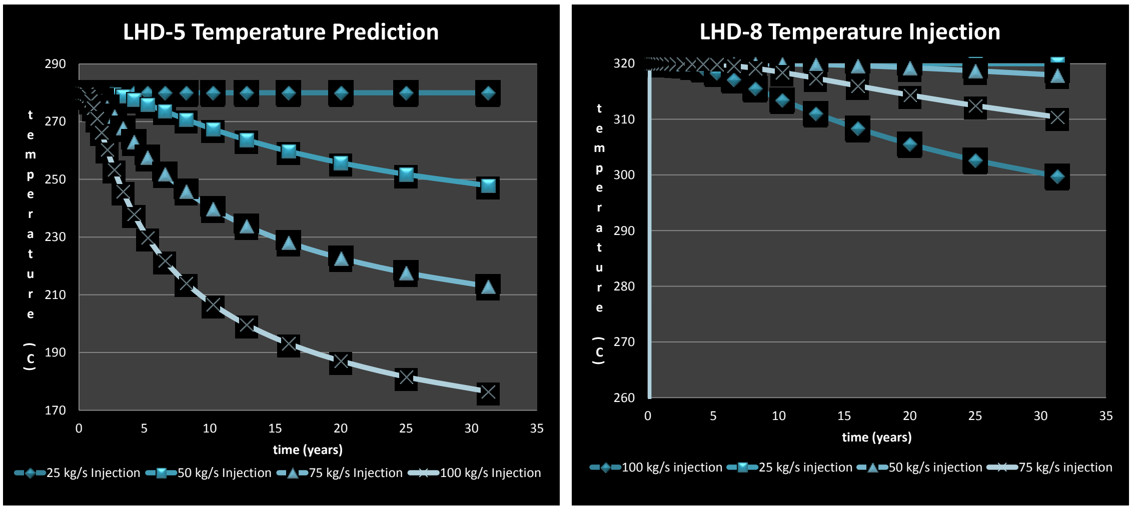

Figure 6: Profile Well LHD-5 and LHD-8

Referring to the single curve tracer profile on figure 3, it could be implied that almost all the fluid recovered in production wells from injection well, move in single layer feedzone. However, the possibility of injected fluid movement through other layer of feedzone might exist if the sampling continued and shows more return curve in result.

Based on the model and prediction, it could be concluded that the connection between injection well and production wells in north area, represented by LHD-5, is quantitatively good but qualitatively not too direct. The mass recovery of LHD-5 is high but the flow velocity is on the average. This could be interpreted as existence of big fractures with low permeability or not continuously connected between the injection wells and production wells. The short distance between them also impact on the connection. Even though the fracture permeability is low, the short distance and the fracture size deliver high mass recovery to the production wells.

Comparing with the production wells located in south block represented by well LHD-8, it could be inferred that the connection between injection well in north and production wells in south controlled by small fracture but directly connected with good permeability. This interpretation based on the rapid flow velocity but low mass recovery.

Combined to geological model of Lahendong Field developed by Ganda et al (1982), it could be predicted that the connection between Injection well and LHD-5 mainly controlled by fracture F4 which is a big fracture but has low permeability. The connection between injection well and LHD-8 mainly controlled by fracture F7 which is a small fracture with high permeability. The flow path between injection well and the production wells in south and north area might be represented by figure 7 below.

Based on the analysis, to reduce negative effect of actual Lahendong Field reinjection strategy for production wells in north block, the injection rate should be controlled around 25 kg/s below 50 kg/s. However, the reduction of injection rate would impact the reservoir pressure in south area where the mass recovery actually low. For compensation, some of the injection should be split off from northern boundary (cluster LHD-7) to other area especially southern boundary where mass extraction is high.

Other strategy that could be implemented to maintain reservoir pressure and temperature is change the cold injection strategy into hot injection strategy. This strategy would reduce the reservoir temperature decline and maintain reservoir pressure by injecting high mass rate to the reservoir. The main considerations of this strategy are the possibility of scaling in the pipeline and the high investment cost in order to change the pipeline design.

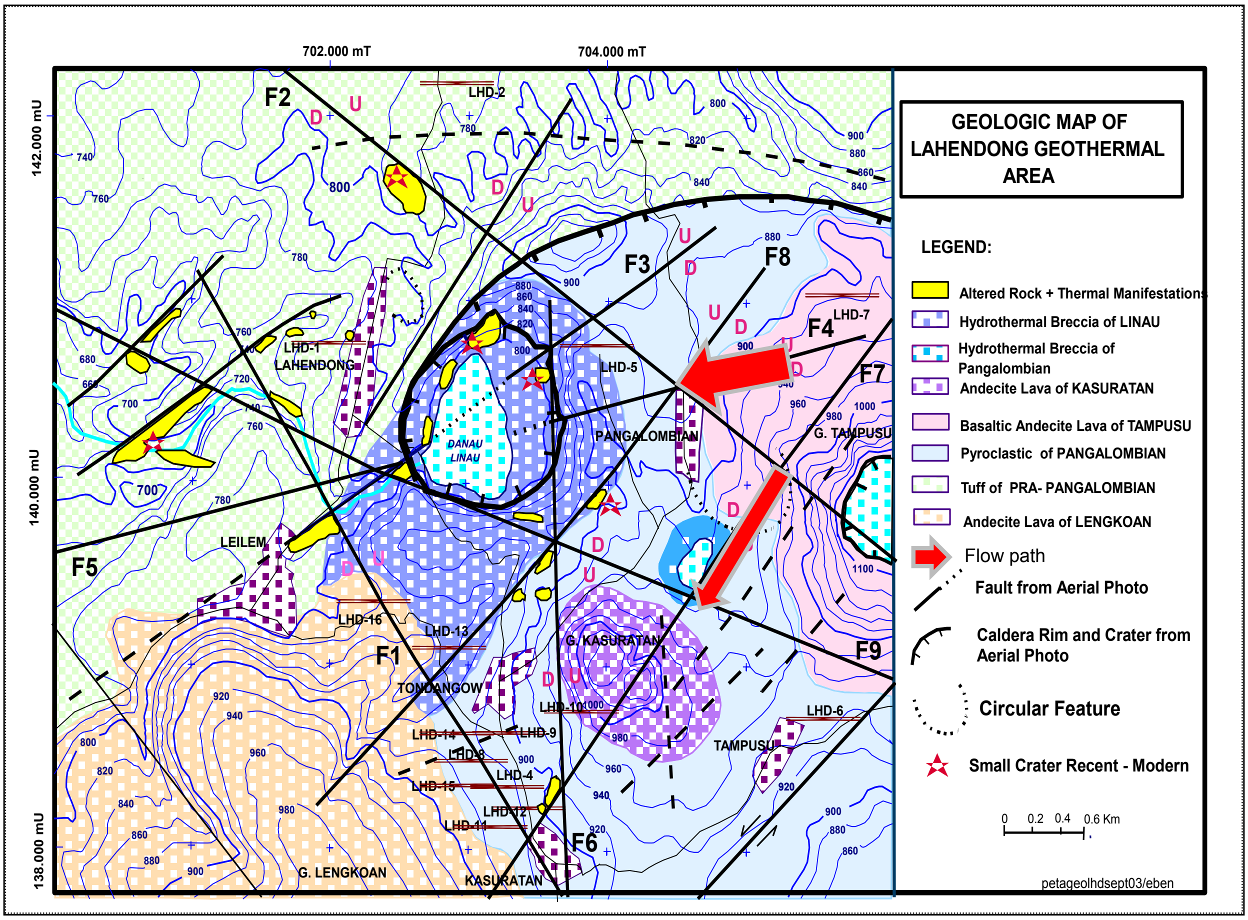

Figure 7: Fluid Flow Path of Lahendong Field

4. CONCLUSIONS

1) Tracer injection program using 1.6 NDSA could indicate flow connection between injection well (LHD-7) and production wells both in north and south area represented by well LHD-5 and LHD-8.

2) Using Axelsson et al analytical method, current cold reinjection strategy of Lahendong field is predicted to affect well LHD-5 significantly by reducing reservoir temperature more than 70 °C after 30 years of injection and breakthrough time in the first year. This strategy would reduce reservoir temperature around 20 °C after 30 years of injection and breakthrough time after third years. The effect of injection predicted might impact similar production wells both in north and south area.

3) The connection between injection well and production wells in north zone is inferred to be along a big fracture with low permeability, whereas in the south zone predicted through small fracture with good permeability.

4) Several improvement to the reinjection strategy could be implemented in order to reduce negative effect of injection fluid to the reservoir.

5) Further study involving tracer analysis of other production wells combined with GGGR study should be continued to determine more comprehensive description of flow paths in Lahendong reservoir.

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